

**DIVISION OF CONSTRUCTION AND RESEARCH
TRANSPORTATION LABORATORY
RESEARCH REPORT**

**CALIBRATION STANDARDS
FOR
NUCLEAR GAGES
DENSITY AND MOISTURE
STANDARDS**

75-30

FINAL REPORT

CA-DOT-TL-2908-3-75-30

DECEMBER 1975

Prepared in Cooperation with the U.S. Department of Transportation,
Federal Highway Administration

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CALIFORNIA DEPARTMENT OF TRANSPORTATION



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16. ABSTRACT <p>A search for suitable materials to serve as calibration standards for nuclear moisture-density gages was undertaken. A series of six blocks were fabricated for these standards. Each standard consisted of stone from a separate source. Three were quarried and cut to suitable size from stone and three were cast of portland cement and selected natural aggregate from separate sources. These were chosen as the calibration standards for all nuclear density gages used by the California Department of Transportation. Questionnaire replies from District Materials Engineers indicated that the use of standardized blocks improved accuracy, uniformity, and flexibility. Also, monetary savings are attributed to this procedure.</p> <p>The research involved the selection of suitable nuclear moisture gage calibration standards which resulted in a recommendation to adopt a series of silica sand water mixtures as the moisture gage calibration standards. The investigation of several soils and materials revealed a greater understanding of moisture gage response to various soil minerals. The results of these laboratory tests indicated the magnitude of gage measurement errors that could occur during moisture determinations.</p>					
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December 1975

FHWA No. F-4-22
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Mr. C. E. Forbes
Chief Engineer

Dear Sir:

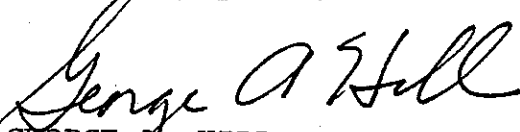
I have approved and now submit for your information this final
research project report titled:

CALIBRATION STANDARDS
FOR
NUCLEAR GAGES

Density and Moisture Standards

Study made by Geotechnical Branch
Under the Supervision of Raymond A. Forsyth, P.E.
Principal Investigator Joseph B. Hannon, P.E.
Jerry C. Chang, P.E.
Co-Investigator Ellsworth L. Chan
Report Prepared by David R. Castanon
Ellsworth L. Chan

Very truly yours,



GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

STATE OF NEW YORK
IN SENATE

January 10, 1907.

REPORT

OF THE

COMMISSIONERS OF THE LAND OFFICE

IN RESPONSE TO A RESOLUTION PASSED BY THE SENATE

APRIL 10, 1906.

ALBANY:

THE STATE PRINTING OFFICE, 1907.

1907.

1907.

1907.

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Appreciation is also extended to Dale Sathre and Frank Champion who performed numerous technical operations with care and precision. Appreciation is also extended to the Materials personnel of the eleven districts for their cooperation in contributing to the evaluation of the standard density blocks, particularly to those who provided additional information to the questionnaires submitted to them.

The contents of this report reflect the views of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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INTRODUCTION

The official use of nuclear moisture-density gages by the California Department of Transportation began in 1966. Prior to this, the Sand Volume Method was the accepted measure of earthwork compaction. The adaption of this application of nuclear technology for compaction control required a personnel transition period of education, experimentation, and correlation between sand volume and nuclear gage measurements.

Development of field test procedures and the training of gage operators were major tasks. The confidence and reliability of the nuclear gage rested in the calibration procedure and the techniques applied by the gage operators. Several days were involved in gage calibration for compaction control at the beginning of each highway project. Soils sampled from the construction site were compacted in large molds at various densities and moisture contents and used for nuclear gage calibration purposes. Consideration of the validity of this procedure presented several questionable areas related to field conditions and gage performance consistency. The remolded soil standards limited the range of densities and water contents found under actual field conditions and did not account for the non-uniform character of soil types encountered on a construction project. Numerous soil types required additional time to produce a separate nuclear gage calibration for each soil.

By employing this calibration procedure, the number of calibration standards were as numerous as the number of highway projects in progress and as varied as the number of soil types tested. The soil standards also precluded a permanent calibration reference from being established. Moisture contents of the soil standards would also slowly diminish, thus resulting in a

continuously changing moisture-density response from the nuclear gage. Reproduction or duplication of the soil standards were extremely difficult, if not impossible to achieve. Reproduction was usually necessary to monitor nuclear gage performance during the construction period.

The problems created by the soil standards necessitated the search for a more desirable and permanent set of calibration standards for all nuclear gages in service. To satisfy this requirement, a program to develop moisture-density standards was initiated as a state-financed research project in July 1967. A subsequent proposal was initiated to conduct the research as a FHWA participating project and was approved in September 1968.

As a result of this research authorization, a set of six master density gage calibration standards and two silica sand water moisture standards were established. The set, three calcareous standards and three siliceous standards, represent the predominant mineralogy of California highway soils. Three of the six density standards were quarried and cut to suitable size for effective use. The remaining three standards were cast of portland cement and selected aggregate. The moisture standards consist of silica sand water mixtures. One standard is kept dry in a sealed container and the second standard is fully saturated with water.

This report contains a brief summary of our experience with these standards. A detailed discussion on their selection and development is presented in the Interim Report for this study (1).

The major emphasis of this final report deals with the evaluation and development of neutron moisture gage calibration standards. Laboratory work, revealed several important facts concerning

the effects of soil mineralogy on moisture gage response. Soil minerals containing hydroxyl ions in their structural lattice usually yield excessive moisture measurements. On the other hand, the presence of mineral elements which absorb thermal neutrons will yield deficient moisture measurements. A silica sand water mixture appears to be the most desirable materials to use as the moisture calibration standards. The absence of mineral hydroxyl ions and thermal neutron absorbing elements permits the moisture gage to respond to the true "free water" content of the soil water matrix. Two solutions to the mineral influence problem are discussed in detail.

Man made soil water substitutes were also explored, but proved to be unsuccessful in one or more aspects.

CONCLUSIONS

Density Gage Calibration Standards

1. The basic density calibration determined on the six stone master density standards is satisfactory for use in compaction control of California soils used in highway construction.
2. Over the range of densities comprised by the master density standards (96 to 173 pcf), the calibration curve appears to be slightly curvilinear when plotted on semilogarithmic paper.
3. The use of a high and a low density standard in each transportation district, in conjunction with the master standards, has greatly improved the uniformity and accuracy of nuclear gage calibration within the California Department of Transportation.

4. The two transportation district reference standards can be satisfactorily fabricated of portland cement and selected aggregates. These reference standards are as stable and uniform as those cut from natural stone.

5. The master density standards have proved to be a satisfactory means of calibrating all nuclear density gages operated by the California Department of Transportation. In addition, the standards serve as an integral part of the specification criteria involved in gage procurement and can be used to determine gage performance.

Moisture Gage Calibration Standards

1. The nuclear moisture gages respond to the total water (Hydrogen) content of a soil. This includes bound or adsorbed water, inter-layer water, hydrates, and hydroxyl water. A water content estimated on the basis of an oven-dry moisture determination reflects only the free, or easily evaporable water.

2. For a given water content, the presence of slow neutron absorbing elements will decrease the response of the nuclear moisture gage. However, the presence of the absorbing elements appears to be a calibration constant.

3. The change in soil water during normal construction activities occurs almost entirely in the soil free water. The results of this research indicate that the free water calibration curves can be assumed to differ only by a constant, which depends on the sum of the effects of the structural water and absorbing elements present.

4. The slope of the nuclear moisture calibration curves is satisfactorily established by testing on reference standards of silica sand and water.

RECOMMENDATIONS

The standard density blocks and silica sand water moisture standard provide a uniform and relatively stable standard for calibration and evaluation of nuclear moisture density gages. The use of the standards has enabled the department to achieve improved accuracy, uniformity of test procedure, interchangeability of gages and monetary savings. On this basis we recommend that all gage users or potential gage users make available a series of permanent standards which are composed of materials which are both uniform and stable with respect to moisture and density. These standards should represent the range of density and mineral compositions which are expected to be encountered during normal use of the gage.

IMPLEMENTATION

The six master density standards and the two silica sand water moisture standards are currently in use by the State of California, Department of Transportation as an integral part of the annual nuclear gage calibration and gage specification compliance test procedures. Each district has been provided with two density standards and two silica sand water moisture standards. On an annual basis the six master density standards are taken to each of the eleven transportation districts for calibration of district gages. This service is also provided to the various cities and counties that employ nuclear gages. For the detailed calibration procedure refer to Transportation Laboratory Test Method No. Calif. 911 which is appended.

DISCUSSION

Evaluation of Gamma-Density Calibration Standards

Since the publication of the Interim Report, procedures for calibrating all Department of Transportation nuclear density gages on the six standard density blocks have been established and are outlined in Test Method No. Calif. 911 (see Appendix). As described by this method, all nuclear density gages are initially calibrated on the six density standards maintained by the Transportation Laboratory at Sacramento, California. The gages are then recalibrated once annually with the six density standards. Between annual calibrations, the gages may be recalibrated on the two reference standards kept by each Transportation District. The two reference standards are also used during the annual calibration procedure, and their location on the standard calibration curve is determined. One reference standard is located in the high density region of the calibration curve (150 to 155 lbs. per cu. ft.) and the other standard is located in the low density region 110 to 115 lbs. per cu. ft. Dense and light weight concrete serve as the district reference standards.

Over 150 nuclear density gages are being used by the California Department of Transportation. In addition, city, county, and private engineering laboratories utilize these standards for their gage calibrations. For the purpose of evaluating the usability of the standard density blocks, questionnaires, concerning the use of the standards, were submitted to each of the eleven District Materials Engineers. On the basis of their replies, it is felt that the original intent of the standards had been accomplished. Improved accuracy, uniformity, flexibility, and monetary savings had been achieved.

Accuracy has been achieved because the standard density blocks are relatively homogeneous materials with stable moisture conditions, enabling accurate density determination. The remolded soil standards previously used varied considerably and proved to be undesirable. Since all gages are now calibrated in a designated manner on the six standards, calibration uniformity was realized. This aspect also helped unite the gage operators to adopt a common procedure for gage use. Due to the common calibration standards, any nuclear density gage in service can be interchanged with any other gage without concern for calibration differences, that is, within the limits of the calibration test variability. Gage substitutions or relocations pose no difficulty to gage reliability, thus gage flexibility was secured. The elimination of the need to compact soil specimens for gage calibration reflects a major savings in man-hours expended. The two permanent reference density standards kept by each district provide a means to monitor gage performance.

Achievement of the goals mentioned above reflect the general comments made by the Transportation Laboratory personnel, who assist and consult with district personnel in nuclear gage maintenance and test procedures throughout the California Department of Transportation. This technical assistance includes the annual gage calibration.

Several correlation studies were also performed to determine the validity of the six density standards and each pair of reference standards maintained by the District Materials Engineers. Compaction control tests, conducted with gages calibrated by the six density standards and gages calibrated by the reference standards indicated similar test results. During the 1972 construction season, tests were performed on five highway projects throughout California. The comparison

of limited test data between the two gage calibrations showed good correlation. Previous comparisons made with gages calibrated on different sets of remolded soil standards indicated very poor correlation results.

Conclusions by Smith, et.al. (2), in their research report "Relative Compaction Study," indicate that standard density blocks calibration curves correlate well with volumetric box (remolded soil) calibration curves for the 6-inch and 8-inch direct transmission mode. In reference to the backscatter mode, they conclude that, "The standard density blocks calibration curve is offset about 2 or 3 pcf from the volumetric box curve in the backscatter mode." Tests recently conducted on another research project displayed very good correlation between gages calibrated on the standard density blocks and gages calibrated on volumetric box standards. These statements indicate that the six standard density blocks are adequate for the densities and compositions of soils used in California highway construction.

The standard density blocks serve as an integral part of the specification compliance testing procedure for all Department gages. The standards are used to determine gage sensitivity to changes in soil density as well as determine, to some degree, gage sensitivity to mineral composition when different soil mineralogy is encountered. The gage's performance, concerning these two major parameters, is clearly defined by the standard density blocks, and provides an important measure of gage quality.

The favorable comments received and the general satisfaction with the standard density blocks, including the nuclear gage procedures and specifications structured around them, indicate that they are providing a valid method for utilization of our nuclear density gages for earthwork compaction control. As

for future use, in addition to gage calibration, the standard density blocks will be used, where applicable, to evaluate suggestions submitted by nuclear gage personnel and the normal changes which come about in the nuclear gage state-of-the-art.

The Moisture Calibration Problem

1. Field Moisture Correlation

In the fall of 1967, research directed at development of calibration standards for nuclear moisture-density gages was undertaken by the California Department of Transportation at the Transportation Laboratory, 5900 Folsom Boulevard, Sacramento, California. Temporary moisture standards having high and low water contents were prepared by compacting a local river sand in molds cut from steel drums. Before compaction, the sand was allowed to attain air-dry equilibrium moisture. It was then compacted similarly in each of the tubs, and the bulk densities of both were calculated.

One tub was constructed with a piezometer and a plastic tube leading to the bottom to permit saturation of the specimen. This sample was flooded until the free water surface was at the sand surface, and all voids were considered saturated. The amount of water added was measured, and checked by weighing the tub and contents before and after adding water. The initial water content of the sand was estimated from oven-dry moisture samples and as a result, the total water content of the saturated moisture standard was known.

The tub containing air-dry sand with no further water added was used as a low moisture standard. Subsequent weighing of this sample indicated little change in moisture content. When the tub was dismantled, the top one to two inches was found

to be slightly drier than at greater depth. However, this had a negligible effect on the nuclear moisture tests taken on that sample.

When a calibration curve established on these standards was compared with one (for the same gage) developed using "oven-dry" field moistures, the two were found to be displaced by about 3 lb. per cu. ft. of water. That is, the indicated water content of a site using the oven-dry calibration was lower than if the sand water calibration was used. It was very evident, however, that the estimated regression through the field data points was essentially parallel to the laboratory calibration. Since these curves were developed independently, it was concluded that the relationship between the two methods of calibration should be investigated further.

2. "Structural" Soil Water

The observed discrepancy of the offset in the parallel moisture calibration curves discussed above was concluded to be due to the presence of moisture, especially in the clay minerals, which was not removed in the oven-dry test. The nuclear moisture gage response is proportional to the hydrogen contained in any form. This may include in addition to the free water: inter-layer water, hydrates, and hydroxyl water. It is easily demonstrated that all of these forms of "structural" soil water are not evaporated at temperatures of 105-110°C. For example, Nutting (3) reports that the kaolin minerals lose an additional 14 percent by weight (approximately) of hydroxyl water between 400 and 800°C, with the ensuing destruction of the kaolinite. The number of hydrogen atoms in hydroxyl water is one half that of the corresponding quantity of free water molecules. Consequently, the nuclear moisture gage would respond to the free water equivalent of the hydroxyl water in kaolinite; or, about 7 percent by weight.

Typical data for some clay minerals are summarized in Table 1.

These are approximate average values showing the trend toward additional water loss at temperatures above 100°C. For the portion of this loss considered to be hydroxyl water, the equivalent free water (one half) is tabulated.

Hydrates such as the zeolites and serpentines also contain significant amounts of water which are not driven off by temperatures of 105-110°C. Also, Lambe reported that a diatomaceous earth retained significant amounts of water at temperatures above 105°C (4). This is apparently caused by the attractive forces of the very large internal surface area of this soil. This water should be similar in behavior to the bound water of the clay minerals.

3. Thermal Neutron Absorption

In 1964, Burn published a report, "Calibration of a Neutron Moisture Meter in Leda Clay" (5). Figure 1 is a reproduction of a graph from that paper showing moisture correlation data for a nuclear gage used on the Leda clay. The plot of nuclear readings versus oven-dry moisture contents of the soil is nearly 6 lbs. per cu. ft. to the right of the reference curve. This is at the opposite extreme of the California field calibration data. Burn's reference curve is based (in part) on silica sand and water standards having known total water content which generally correspond to the California Department of Transportation standards previously described.

Burn speculated that the discrepancy between the two calibrations was due to the presence of iron in the clay which absorbed the neutron flux. He observed, as is apparent in the figure, that the displacement between the two curves appears to be a constant for that soil.

4. Summary

It has been shown that if the nuclear gage is calibrated by oven-dry moisture determinations, it can indicate a water content of field soils as much as plus or minus 6 lbs. per cu. ft. of water from that based on an inert system such as silica sand and water, Figures 1 to 5. However, in earth construction, the free soil moisture is the factor which requires control. This has been shown to be a variable percentage of the total soil water to which the nuclear gage responds. Consequently, unless a consistent relationship can be demonstrated to exist between a calibration based on standards of known water content and the free water content of individual soils, the users of the gages are forced to calibrate by field correlation. This is difficult, and in some cases impossible to do, since a sufficient range of data is often not available to establish the slope of the curve with any degree of confidence.

Experimental Procedure

The experimental procedure involved the careful fabrication, and testing with nuclear moisture gages of four soil water systems in large molds. They were:

- 1) A commercial silica sand
- 2) A commercial kaolin clay
- 3) A typical clayey field soil
- 4) An expanded shale

The approximate structural water content of the soils was determined on the basis of high temperature evaporative tests, mineral identification, and differential thermal analysis (DTA), Tables 2 to 5. Therefore, by exercising careful control of the amount of water added, both the free water and total (equivalent) water content of the individual samples were closely estimated.

The physical data concerning the dimensions, volumes, densities, and water contents of all samples tested with the nuclear moisture gages in the experimental program are presented in Table 6. The dimensions and volumes of the samples were of sufficient size to ensure that they would essentially represent infinite soil mass for testing with the gages.

The top surfaces of most of the samples were protected by covering them with a layer of polyethylene plastic. The plastic was tested and found to have a negligible effect on test results by taking readings with and without the covering.

1. Silica Sand Samples

Silica sands from two sources were obtained, which were 99.7 to 99.9 percent pure SiO_2 . The approximate grading of the sands is given in Table 2.

Four samples were fabricated from these sands. They were:

- 1) A-70-W. This sample was compacted dry in approximately 2-inch lifts with an electric impact hammer using a plywood disc to confine the sand. The sample was provided with a piezometer and a perforated plastic tube to prevent saturation from within. The (W) in the notation indicates a "wet" or saturated sample.
- 2) E-25-W. This sample was prepared similarly, except that the No. 25 sand was used.
- 3) A-70-200-W. A ground silica sand (No. 200 flour) was uniformly mixed with the No. 70 sand to reduce the void space, so that a lower saturated water content was obtained.

- 4) E-25-D. The dry silica sand standard (D) was fabricated with the No. 25 sand. The moisture content of this sand when initially compacted was hardly detectable. After exposure to the atmosphere in the test area for a period of several months, the moisture increase was upward to 0.2 percent.

An attempt was also made to fabricate a partially saturated sample by compacting the moistened sand in increments. Polyethylene plastic was used to prevent migrations of water. However, sufficient intra-layer water movement was found to occur in the layers which affected the gage readings and made this type of specimen unsatisfactory.

2. Kaolin Samples

A kaolin clay of high purity was obtained from Ione, California. The physical properties and chemical analysis provided by the producer are shown in Table 3.

An independent analysis of a sample of this clay using X-ray diffraction and differential thermal analysis (DTA), was conducted at the Transportation Laboratory. The clay was identified as a typical kaolin, with little or no indication of the presence of other clay minerals.

High temperature evaporation tests were conducted with oven-dry samples of the Ione Kaolin. These samples lost 0.1 percent by weight between 105 and 400°C, and 12.2 percent by weight between 400 and 600°C. This loss in weight was considered to be primarily hydroxyl water, and an equivalent water loss between 105 and 600°C of 6 percent was presumed for the purposes of the study.

Two samples of the kaolin were then prepared in large molds for testing. The dimensions and volumes of the samples are given in Table 6. These two samples were prepared similarly, except that different amounts of free water were added to each. The intent was to obtain as high (H) and as low (L) a water content as possible, with uniform compaction, and not too great a difference in the dry density of the two. The amount of free water to add was estimated from preliminary tests. Representative oven-dry samples were also taken and checked when the sample was dismantled after completion of the testing. One of the kaolin samples (the Kaolin-H) was dried in a 105-110°C oven, and then retested with the nuclear moisture gages.

3. Field Soil Samples

Two samples of a typical field soil were prepared and tested similarly at a high and low free water content. A third sample was fabricated by compacting the material in an oven-dry condition. The grading and mineralogy of the soil are presented in Table 4.

High temperature evaporation tests were also conducted on oven-dry samples of the field soil. A loss of 0.5 percent by weight was recorded between 105 and 400°C, and 2.2 percent between 400 and 600°C. The loss in weight between 105 and 600°C was assumed to indicate an equivalent water content of 1.5 percent by weight.

4. Expanded-Shale Sand Samples

Five samples were prepared of an expanded-shale sand. This material is manufactured by expanding sand-sized particles of montmorillonitic shale by heating in a rotary kiln to temperatures of approximately 2,000°F. The grading of the expanded shale sand, and the manufacturer's chemical analysis is given in Table 5.

One of the expanded-shale sand samples (ES-20.6, Table 6) was prepared by compacting, and then saturating. The (ES-dry) sample was left in a dry or "as compacted" state. The remaining three expanded-shale sand samples were prepared by moistening the shale sand to intermediate water contents, and then compacting. Due to the absorbent nature of the calcined shale, the procedure appeared to work satisfactorily, with little discernible migration of water during the period of testing. The water contents of several of the shale sand samples were checked by removing the material in layers, and oven drying the entire increments.

5. Concrete Blocks

Consideration was also given to the prototype concrete density gage calibration standards. The high quantity of hydrated compounds present in these standards provided sufficient hydrogen content to satisfy both low and high water content equivalents. More data, however, remains to be gathered on their ability to maintain a constant degree of hydration.

Other materials considered for use as a moisture standard included phenolic resin and silica sand, polyethylene and glass, and epoxy are described below.

6. Phenolic Resin and Sand

Phenolic resin coated sand was placed in two different molds and each mold heated so as to fuse the sand together. The molds, 1.2' height by 1.9' diameter, consisted of metal barrel ends whose approximate individual volumes were 3.25 cubic feet. The amount of resin content was varied in both molds so as to represent, in terms of hydrogen content, high and low water equivalents. The reason for abandoning the phenolic resin and

sand combination was because the equivalent H_2O content in the high moisture sample was too low and the vendor could not fabricate a sample with a higher phenolic resin content.

7. Epoxy

Testing with 4" thick epoxy and sand blocks was conducted but these were found to be too thin and larger masses of epoxy and sand were difficult to control.

8. Polyethylene and Glass

This combination of materials was considered but was not tested.

Nuclear Moisture Gage Data

The soil samples were not necessarily fabricated or tested with the nuclear gages in the order presented, nor was it possible to retain all samples so that they could be tested concurrently.

To compensate, as each new sample was being tested, all available samples were read. The average of these readings on each available sample was then plotted against the sample free water in Figures 2 and 3 and against the estimated total water content in Figures 4 and 5.

Two nuclear soil gages were used during this study. Gage A is an older unit that has been found to be relatively stable over an extended period of time. The source contained in this gage is 4.5 mc Radium 226-Beryllium. Gage B is of more recent manufacture, and contains a 50 mc Americium 241-Beryllium neutron source.

1. Free Water Correlation Data

Figures 2 and 3 illustrate the response of Gages A and B plotted against the free water content of the samples. The curves are drawn by visual "best fit". For Gage A, the calibration curves for the four soil water systems are essentially parallel, except for the expanded shale at the lower water contents. The readings taken with Gage B indicate a somewhat greater variation in the slope of the individual calibration lines for the four soil water systems than did those of Gage A.

The data for the expanded-shale water system reflects a high degree of neutron flux absorption. A report by the Oklahoma Department of Highways presents a similar datum point for an expanded-shale water sample tested by them (6). The chemical analysis of the shale sand indicates a total of about 6 percent of iron and potassium present in the material, which would not seem sufficient to cause the amount of absorption shown.

The oven-dry expanded shale sample (ES-dry) plotted very closely to the dry silica sand sample (E-25-D) in Figures 2 and 3.

This suggests that a certain level of thermal neutron activity is required before the capacity of the material to absorb thermal neutrons becomes saturated. At some water content, this absorptive capacity of the soil begins to be satisfied. Thereafter, the production of thermal neutrons with change in water content is almost as though the absorptive elements were not present. Above this critical water content, the calibration curves for soils with absorptive elements for thermal neutrons appear to be reasonably parallel to the silica sand calibration curve.

The assumption that the net effect of the presence of structural water, and slow neutron absorbing elements in a soil, is a calibration constant; is undoubtedly an over-simplification. However, it is concluded that the slope of a calibration curve

determined using standards of silica sand and water should be satisfactory for nuclear gage moisture determinations on most soils. An exception may have to be made for those containing highly absorptive elements, especially at water contents below 6 lbs. of water per cu. ft. The extent to which such materials may be encountered in soils used in highway construction is not known.

2. Total Water Correlation Data

Figures 4 and 5 show the average nuclear gage count ratio readings plotted with respect to the estimated total water content of the samples. Most of the moisture data for the clay soils now plot either on, or to the right of the silica sand calibration curve. It is concluded that nuclear moisture measuring instruments do respond to the structural water, as well as to the free water. However, the effect of the hydroxyl water does not appear to be directly proportional to the hydrogen content. This is to be expected, since the bonding of the hydrogen atom to the soil minerals probably reduces its capacity to thermalize the fast neutrons emitted by the radioisotope in the gage (7, 8).

Mineralogical Effects on Moisture Measurements

A need to determine the amount of influence exerted by soil mineralogy on moisture measurements was identified during our laboratory experiments. Once the influence was established, experimental means to correct moisture gage behavior could be attempted. Four soil types, having the physical and chemical properties listed on Tables 7, 8 and 9, were fabricated in round containers (Photos 1 & 2 and Figures 6 & 7) similar to those used for the silica sand moisture calibration standards (Photo 3). Each air-dry soil type, placed in 2-inch lifts, was consolidated with an electric impact hammer. A plywood disc covering the entire surface of the lift confined the soil during compaction.

The clay minerals have an abundance of hydrate compounds and hydroxyl ions, which generally cause a neutron moisture gage to indicate a higher water content than actually exists in the soil. The bound water held in the mineral lattice effectively thermalize the fast neutrons entering the soil. A container of bentonite and a container of kaolinite were fabricated to determine the bound water effects on moisture gage measurements. In their air-dry state, the bentonite water content, as determined by the 105°C gravimetric method was 6.9 pcf. Similarly, the kaolinite air-dry moisture was found to be 0.4 pcf. The nuclear moisture gage count rates were recorded for these clays using an experimental gage (9,10) and plotted on the silica sand calibration curve (Figure 8) above their respective air-dry moisture contents.

The bentonite contains hydrates and hydroxyl ions which would tend to give a higher thermal neutron count rate and therefore signify a higher moisture content. However, this bentonite contains other elements which act as thermal neutron absorbers. The absorption effect, in this case, appeared to override the thermalizing effect. As a result, the data point on Figure 8 plots below the silica sand calibration curve. The opposite was observed from the kaolinite test. The amount of thermal absorbers (iron) present in the kaolinite was approximately one-tenth the amount present in the bentonite. Therefore, the increased neutron thermalization exceeded the absorption, resulting in an increased thermal neutron count rate. The data point in this instance plotted above the silica sand calibration curve.

Tables 10 and 11 are abridged listings of elements which thermalize fast neutrons and capture thermal neutrons respectively. A brief inspection of these tables, in addition to a review of the element oxides tabulated for the kaolinite and bentonite (Table 8) substantiate this line of reasoning.

Thermal neutron absorption was also investigated by placing an expanded shale, containing 5 percent iron, under the moisture gage. The large amount of iron compounds and oxides of this soil, sold under the trade name, "basalite", was expected to absorb a noticeable quantity of thermal neutrons. As noted by the bentonite test results, the basalite data point should plot below the silica calibration curve. Water was added to the basalite container producing a 17.7 pcf water content. Moisture gage measurements were not made on the air-dry basalite soil prior to saturation of the container.

The test results verified our hypothesis; however, the presence of the high water content probably overshadowed the full effect of the iron. Figure 8 shows the data point below the silica curve. A lesser water content would possibly have revealed a greater absorption influence.

Another strong thermal neutron absorber, boron, produced a significant amount of thermal neutron absorption. The soil contained 2.08 percent boron, in addition to other less effective absorbers. The chemical analysis is listed in Table 8. Water, in this case, was not added to the soil. The air-dry moisture determined by the 105°C gravimetric method was 2.7 pcf. The data point from the moisture gage measurement reduced the expected thermal neutron count rate by approximately 35 percent. Note the position of the boron soil data point on Figure 8.

Our definition of moisture gage measurement error is graphically defined by the horizontal distance in pcf water content of the data point from the silica sand calibration curve. Three nuclear gages, each having a different moisture gage design, were used to measure the water content of the four soil types employed to explore mineral induced error. The measurement errors recorded from each gage are presented in Table 9.

The experiments have clearly shown that mineral composition of the soil is extremely influential in deciding the credibility of moisture gage measurements. Further consideration is being given to this area of study. Recommendations may be advanced for adopting some soil mineral as a standard for determining the measurement error of commercial gages, as well as define error limitations acceptable for our procedurement specifications.

Application

1. "Offset" Method

For specific soils, where an equivalent oven-dry moisture calibration curve for the nuclear gage is desired, a moisture sample is taken at the site of a nuclear moisture reading. The density of the location must be determined by nuclear or other means. The oven-dry moisture in lbs. per cu. ft. of water is calculated, and plotted against the nuclear gage moisture reading. A calibration curve for that soil is drawn through the point and parallel to the sand water reference calibration.

This procedure has two disadvantages: 1) It is only good for the particular soil and 2) any errors in the estimates of moisture or density are reflected in the calculated moisture. An alternate and preferred method is discussed as follows.

2. "Approximate Wet-Weight" Method

A practical method of compaction control utilizing only a wet density correction based on the slope of the moisture calibration curve can be demonstrated. The procedure is especially applicable to structural section materials, for which it is often possible to pre-establish a satisfactory compaction standard. The concept is similar to that of the so-called

"wet-weight" method of compaction control used by California (11) and others. This procedure is predicated on expressing the wet density of a soil, and the laboratory control density, in terms of the same moisture content. The above procedure contains a slight approximation, but the percentage is close to that calculated on the basis of the "exact" wet or dry weight methods.

As an example, suppose that it has been established that a certain soil should have a wet density of 135 lbs. per cu. ft. at some definite (but unknown) water content. This unknown water content was present in the material when it was obtained for laboratory compaction testing. Assume also that a nuclear moisture gage had been used to test the location where the soil was obtained. At the time of removal it was found to have a water content of (x) lbs./cu.³. At a later time, a site with similar soil is tested, and found to have a wet density of 140 lbs. per cu. ft. with $(x+3)$ water content. The wet density of the site in terms of the water content at which the control had been established is $(140 - 3)$, or 137 lbs. per cu. ft. This equivalent wet density is greater than the 135 lbs. per cu. ft. previously established as a minimum control density. Thus, if the slope of the nuclear moisture calibration curve is correct, it has been found that the density of the site is satisfactory without knowing its actual water content.

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TABLE 1

APPROXIMATE WATER LOSS OF VARIOUS MINERALS, 100 TO 800°C

Mineral	<u>Temperature °C</u>							<u>Structural</u> <u>Water</u> Total (equiv) H ₂ O loss	
	<u>100</u>	<u>200</u>	<u>300</u>	<u>400</u>	<u>500</u>	<u>600</u>	<u>700</u>	<u>800</u>	
Kaolin Halloysite									
			Little loss		Approx. 14% by wt. OH ⁻ (equiv. H ₂ O loss = 7%)				7%
Montmorillo- nite Smectite			Approx 3% loss inter-layer H ₂ O		Approx 5% loss OH ⁻ (equiv. H ₂ O = 2½%)				5½%
Vermiculite			Approx. 8% loss inter-layer, cation hydrates			Approx. 3% OH ⁻ (equiv. H ₂ O = 1½%)			9½%
Illite (Mica group)			Gradual loss 2% (presumed H ₂ O)		OH ⁻ loss est. 4½% (equiv. H ₂ O approx. 2%)				4%
Chlorite			Little loss			OH ⁻ loss approx. 12% (equiv. H ₂ O = 6%)			6%
Sepolite			Gradual loss to 10% (presumed H ₂ O)		OH ⁻ , gradual loss to 6% (equiv. H ₂ O = 3%)				13%

Clay mineral data estimated from Grim (12)

TABLE 2

SILICA SAND GRADING

Identification	E-25	E-85	No. 200	A-70
<u>Fineness</u>	<u>25.88</u>	<u>84.42</u>	<u>---</u>	<u>65</u>
<u>Sieve</u>	(Percent Retained)			
20	2.2			
30	38.6			
40	57.6	0.2		0.6
50	1.4	2.4		3.9
60				9.3
70	0.2	10.0		20.5
80				22.1
100		45.0		31.2
140		20.0	1.0	11.6
200		11.0	4.0	0.7
270		2.4	6.0	
325		1.0	9.0	

TABLE 3

IONE KAOLIN, PHYSICAL AND CHEMICAL DATA

Physical Properties:

Specific Gravity	2.60
Moisture (max.) %	0.5 - 1.0
Particle Size, %	
Minus 2 microns	50 - 55
Plus 5 microns	20 - 25
pH	4.5 - 5.5
Water of Plasticity, %	31.9
Average Particle Size	2.2 microns

Chemical Analysis:

Silica, %	45.0 - 47.0
Alumina, %	37.5 - 39.0
Iron Oxide, %	0.3 - 0.5
Titanium Dioxide, %	1.5 - 2.0
Ignition Loss, %	13.0 - 14.0

TABLE 4

FIELD SOIL, GRADING AND MINERALOGY

<u>Grading</u>		<u>Mineral Identification</u>	
<u>Size</u>	<u>% Passing</u>	<u>Mineral</u>	<u>*Approx. %</u>
3/4	100	Quartz	25 - 30
1/2	84	Feldspar	10 - 15
3/8	73	Chlorite	10 - 15
#4	52	Mica	5
8	41	Hornblende	5
16	31	Misc. Clay	5 - 10
30	23	Talc	2 - 3
50	18	Augite	2 - 3
100	15	Other Xtaline	5
200	13	Amorphous	15
5 micron	8		
1 micron	6		

*These percentages are estimated from X-ray diffraction data.

TABLE 5

EXPANDED SHALE-SAND, GRADING & CHEMICAL ANALYSIS

<u>Sieve</u>	<u>Percent Passing</u>	
	<u>(Basalt Rock Co.)</u>	<u>Translab</u>
#4	99	
8	82	82.6
12		52.6
16	56	
30	36	33.3
50	23	22.1
100	12	13.5
200		6.5

	<u>Chemical Analysis</u>	
	<u>"Raw" Shale</u>	<u>Calcined Shale</u>
SiO ₂	59.2	62.8
Al ₂ O ₃	20.0	21.7
CaO	2.6	3.2
Fe ₂ O ₃	3.3	4.4
MgO	2.7	3.3
Na ₂ O	2.6	2.6
K ₂ O	1.6	1.6
H ₂ O	8.0	0.0
Ignition Loss	Trace	0.4

TABLE 6

PHYSICAL DATA FOR THE EXPERIMENTAL SOIL-WATER SAMPLES

Sample	Physical Description			Volume (cu ft)	Density (lbs/cu ft)		Water Content (lbs H2O/cu ft)			** Legend
	Shape	"D" (ft)	Depth (ft)		Wet	Dry	Free	Struct.	Total	
A-70-W	Cylindrical	1.87	0.94	2.63	125.4	100.9	24.5	-	24.5	0
E-25-W	"	"	0.92	2.55	130.2	110.9	19.2	-	19.2	0
A-70-200-W	"	"	0.87	2.43	123.9	109.6	14.3	-	14.3	0
E-25-D	"	"	1.19	3.31	-	111.7	-	-	-	0
Kaolin-H	Octagon	1.50	1.17	2.31	97.1	77.9	19.2	4.7	23.9	
Kaolin-L	Rectangular	1.00	1.50	2.25	80.1	70.7	9.4	4.2	13.6	
Kaolin-H(dry)	Octagon	1.5	1.17	2.31	-	77.9	-	4.7	4.7	
Field Soil-H	Octagon	1.50	1.17	2.31	146.0	131.9	14.1	2.0	16.1	
Field Soil-L	Rectangular	1.00	1.50	2.25	137.4	129.8	7.6	2.0	9.6	
Field Soil(dry)	Cylindrical	1.87	1.22	3.29	89.9	89.9	-	1.4	1.4	
ES-20.6	Cylindrical	"	0.95	2.76	109.2	87.0	22.2	-	22.2	x
ES-17.4	"	"	0.94	2.64	94.4	77.0	17.4	-	17.4	x
ES-12.0	"	"	0.94	3.62	93.8	81.8	12.0	-	12.0	x
ES-6.0	"	"	1.14	3.27	88.2	82.1	6.1	-	6.1	x
ES-(dry)	"	"	1.19	3.29	88.6	88.2	0.4	-	0.4	x

* Equivalent water content

** As used in Figures 2 and 3

NOTE: The dimension "D" is the least top surface dimension.

Table 7

PHYSICAL DATA FOR CHEMICAL ERROR PRONE
MOISTURE TUBS

<u>Moisture Tub</u>	<u>Dia. (ft)</u>	<u>Height (ft)</u>	<u>Volume (ft³)*</u>	<u>Wet Density (lbs./ft³)</u>	<u>Moisture₃ (lbs./ft³)</u>
Silica (Wet)	1.996	1.2144	3.800	130.46	18.8
Silica (Dry)	1.997	1.2186	3.817	112.22	0
Bentonite	1.994	1.3296	4.138	69.8	6.9
Boron	1.994	1.259	3.913	98.8	2.7
Basalite	1.998	1.150	3.581	112.5	17.7
Kaolinite	1.979	1.168	3.62	50.8	0.4

* Volume was determined by use of water.

Table 8

CHEMICAL ANALYSIS FOR CHEMICAL ERROR PRONE
MOISTURE TUBS

<u>Kaolinite Tub*</u>	<u>%</u>	<u>Bentonite Tub*</u>	<u>%</u>
SiO ₂	45-47	SiO ₂	56.42
Al ₂ O ₃	37.5-39	Al ₂ O ₃	23.62
Fe ₂ O ₃	0.3-0.5	Fe ₂ O ₃	1.64
TiO ₃	1.5-2.0	Mn ₃ O ₄	0.04
Na ₂ O ₃	0.0-0.2	CaO	0.62
K ₂ O ₃	0.1-0.3	MgO	4.24
Ignition Loss	13.0-14.0	Na ₂ O	0.07
		K ₂ O	0.01
		H ₂ O (@ 110°C)	6.13
		Ignition Loss	7.18
<u>Boron Tub*</u>	<u>%</u>	<u>Basalite Tub**</u>	<u>%</u>
B	2.08	Quartz	20-25
Cd, Fe, H	0.47	Feldspar	5-10
Quartz	57	Fe	5
Mixed Layer Clays	15-20		
Feldspars	10-15		
Calcite	<5		
Biotite	<5		

*Chemical analysis by wet laboratory analysis and mineral analysis by Differential Thermal Analysis (DTA) and X-ray Defraction.

**Analysis by Differential Termal Analysis (DTA) and X-ray Defraction. Remaining percentages could not be determined because the crystallinity of this sample was largely destroyed by the high temperature it had been subjected to.

Table 9

MINERAL INDUCED ERROR OF MOISTURE GAGE MEASUREMENTS

<u>Fast Neutron Moisture Gage</u>	<u>Soil Type**</u>		
	<u>Boron</u>	<u>Bentonite</u>	<u>Kaolinite</u> <u>Basalite</u>
Commercial Gage "A"	-2.9	-1.8	+0.6 -0.6
Commercial Gage "B"	-2.6	-1.7	+1.4 -0.5
Experimental Gage*	-2.5	-0.5	+0.9 -0.5

* The experimental gage was designed and constructed by Transportation Laboratory personnel

** Units are lbs. of H₂O/cu. ft.

Table 10

Relative Effectiveness of Elements in
Slowing Down Fast Neutrons (13)

<u>Element</u>	<u>Average number of collisions required for thermalization</u>	<u>Element</u>	<u>Average Number of collisions required for thermalization</u>
Hydrogen	18.2	Silicon	262
Boron	104.5	Phosphorus	288
Carbon	115.4	Sulfur	298
Nitrogen	133.5	Chlorine	329
Oxygen	152	Potassium	362
Sodium	215	Calcium	371
Magnesium	227	Iron	514
Aluminum	251	Cadmium	1028
		Uranium	2169

Table 11

Relative Absorption of Capability of Some Elements
for Thermal Neutrons (13)

<u>Element</u>	<u>*Barns</u>	<u>Element</u>	<u>*Barns</u>
Cadmium	2450	Sulfur	0.520
Boron	755	Sodium	0.505
Indium	196	Calcium	0.44
Gold	98.8	Hydrogen	0.332
Lithium	71.0	Aluminum	0.230
Silver	63.0	Phosphorus	0.200
Chlorine	33.6	Silicon	0.160
Iron	2.53	Magnesium	0.063
Potassium	2.07	Carbon	0.0034
Nitrogen	1.88	Oxygen	0.0002

* A "burn" or "Fermi" is a measure of the probable cross-sectional target area.

CALIBRATION CURVE FOR LEDA A CLAY (5)

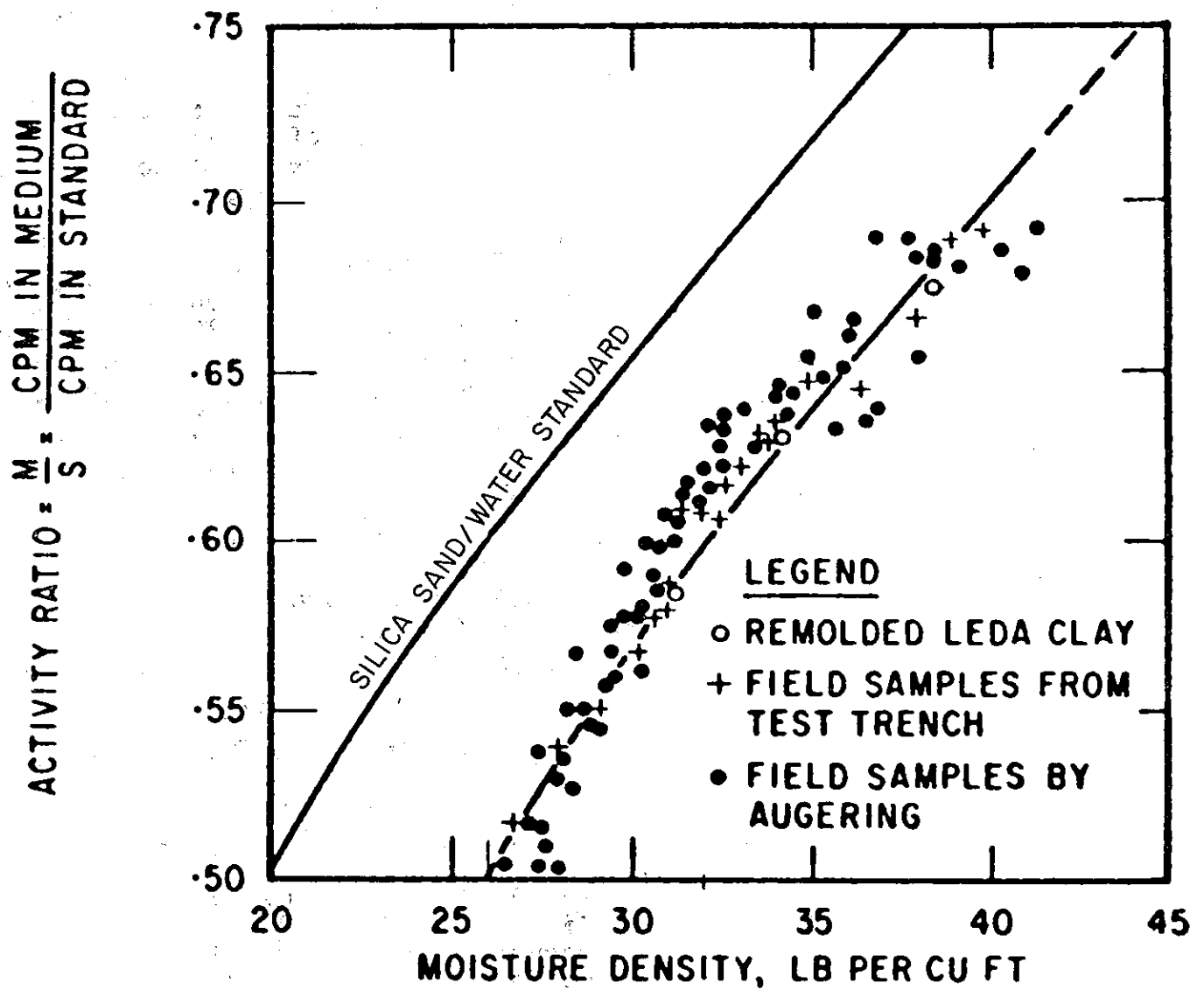


Figure 1

NUCLEAR FREE MOISTURE CORRELATION TEST DATA GAGE A

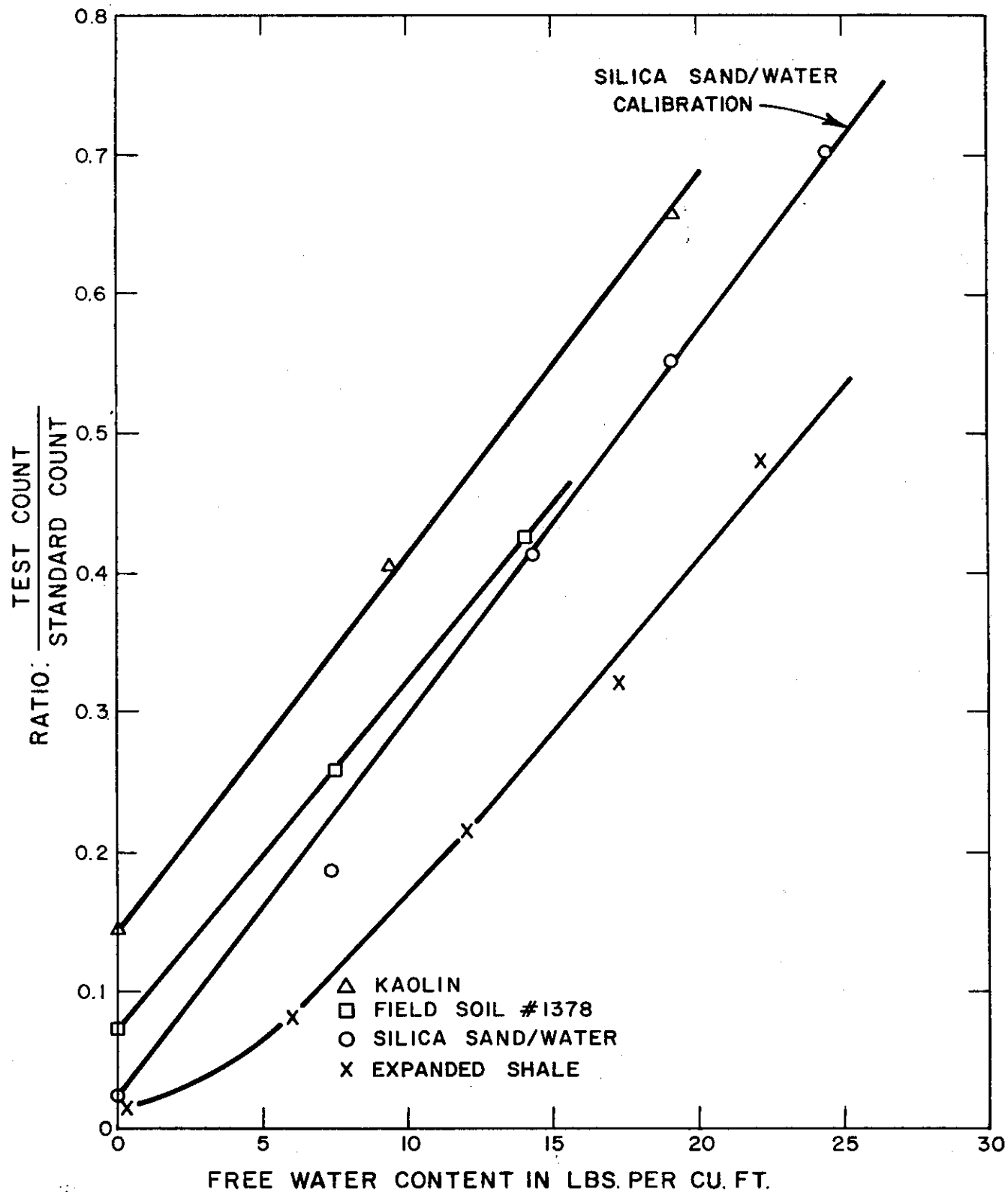


Figure 2

NUCLEAR FREE MOISTURE CORRELATION TEST DATA GAGE B

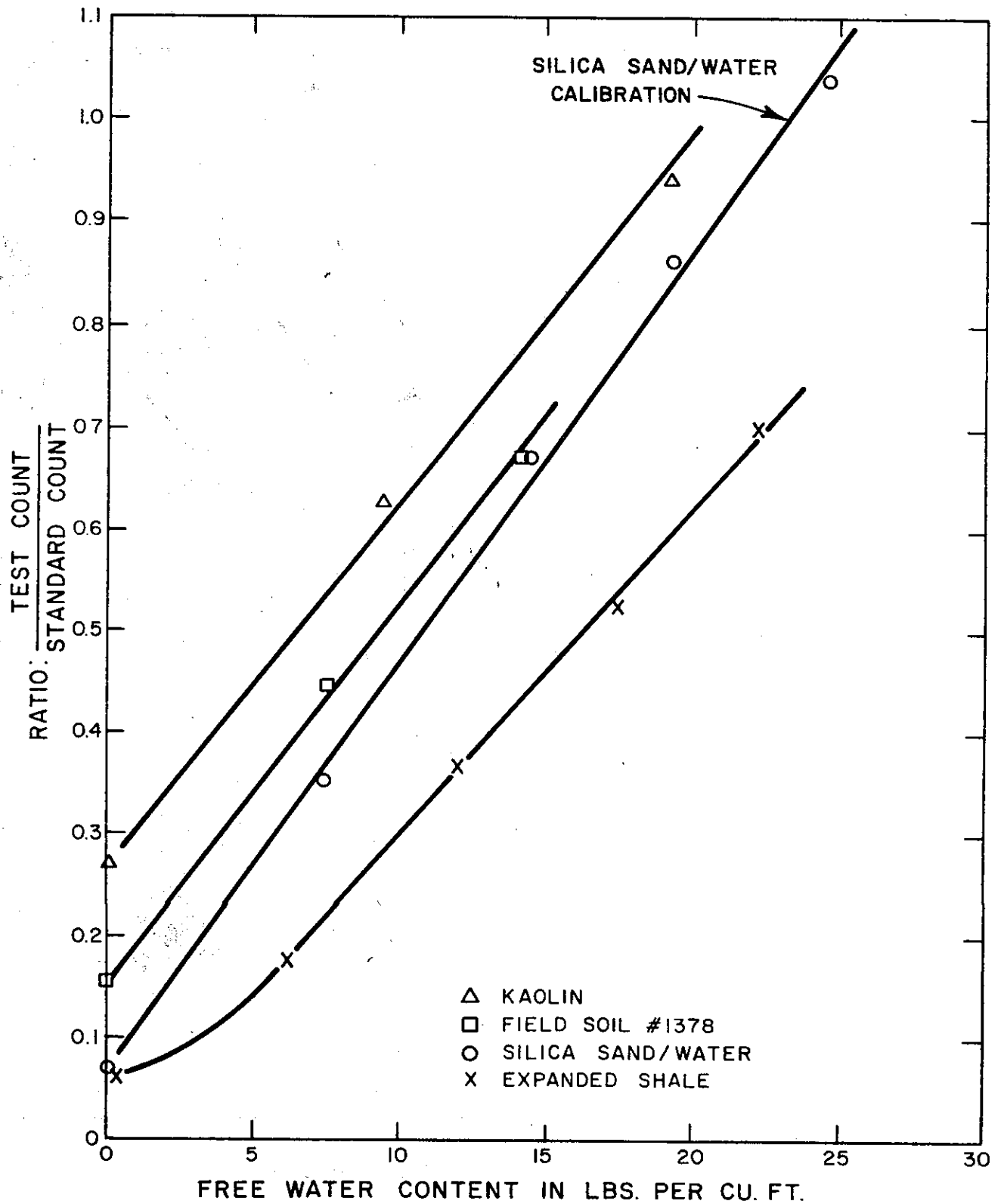


Figure 3

NUCLEAR TOTAL MOISTURE CORRELATION

TEST DATA

GAGE A

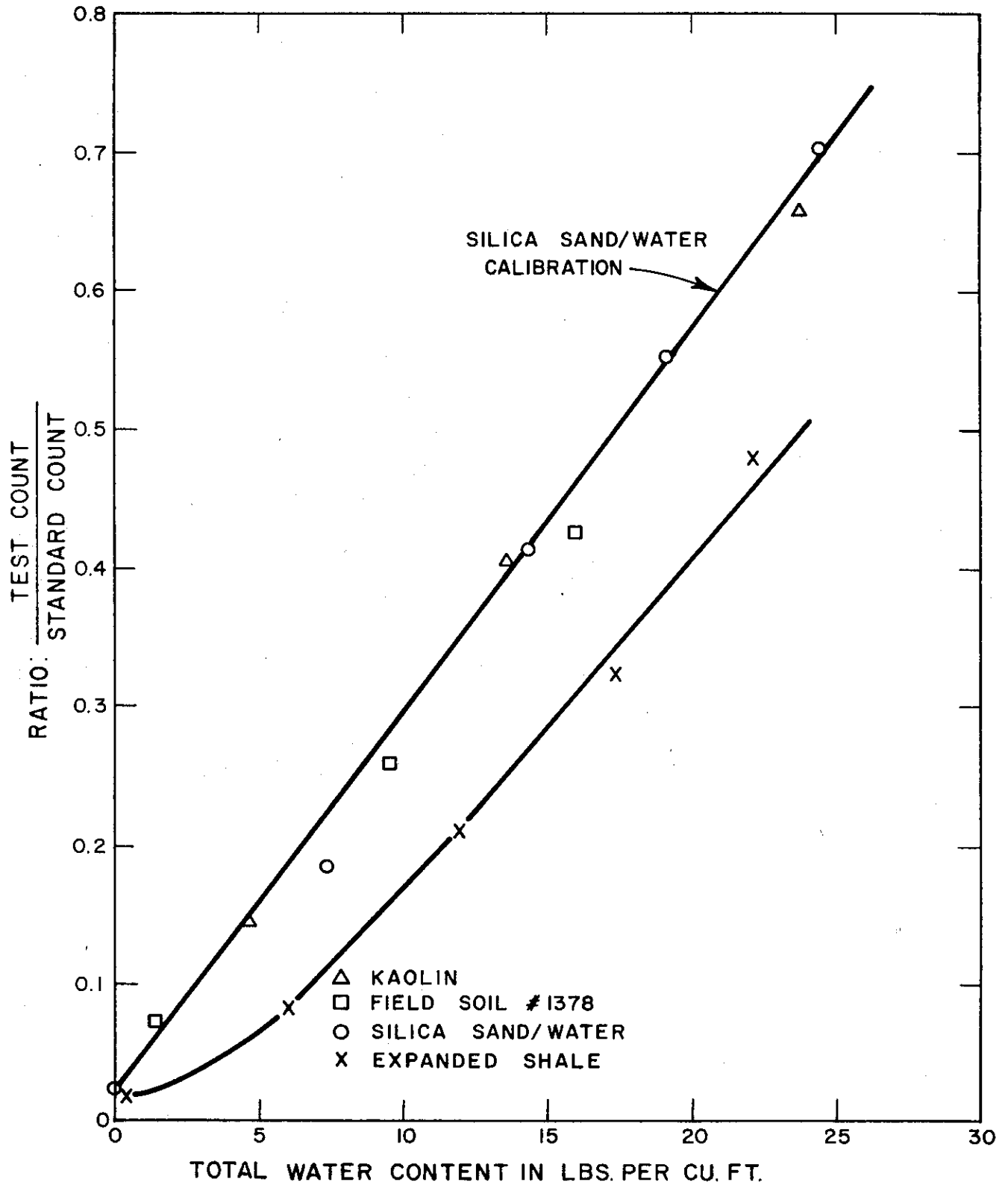


Figure 4

ADITA / NUCLEAR TOTAL MOISTURE CORRELATION TEST DATA GAGE B

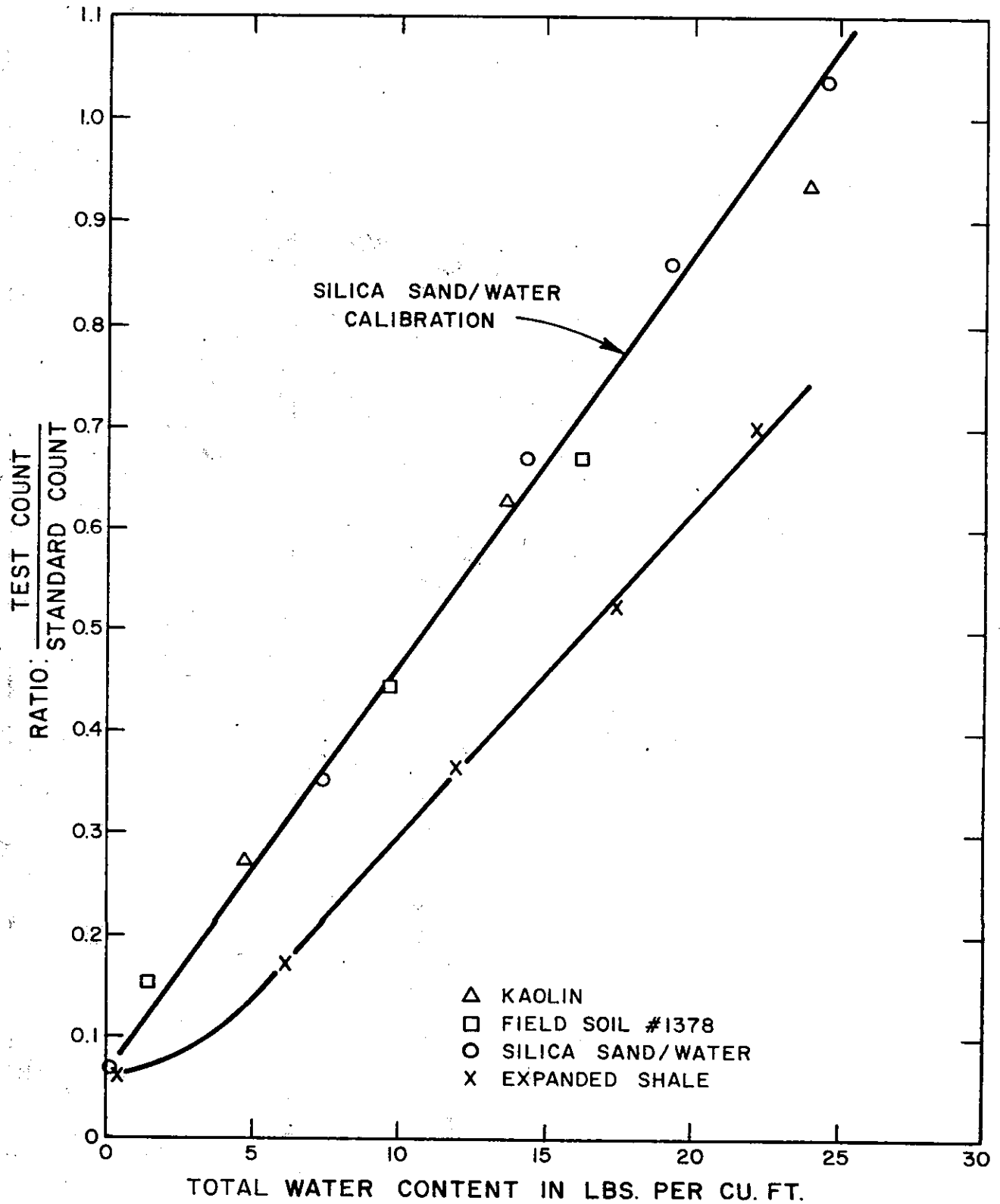
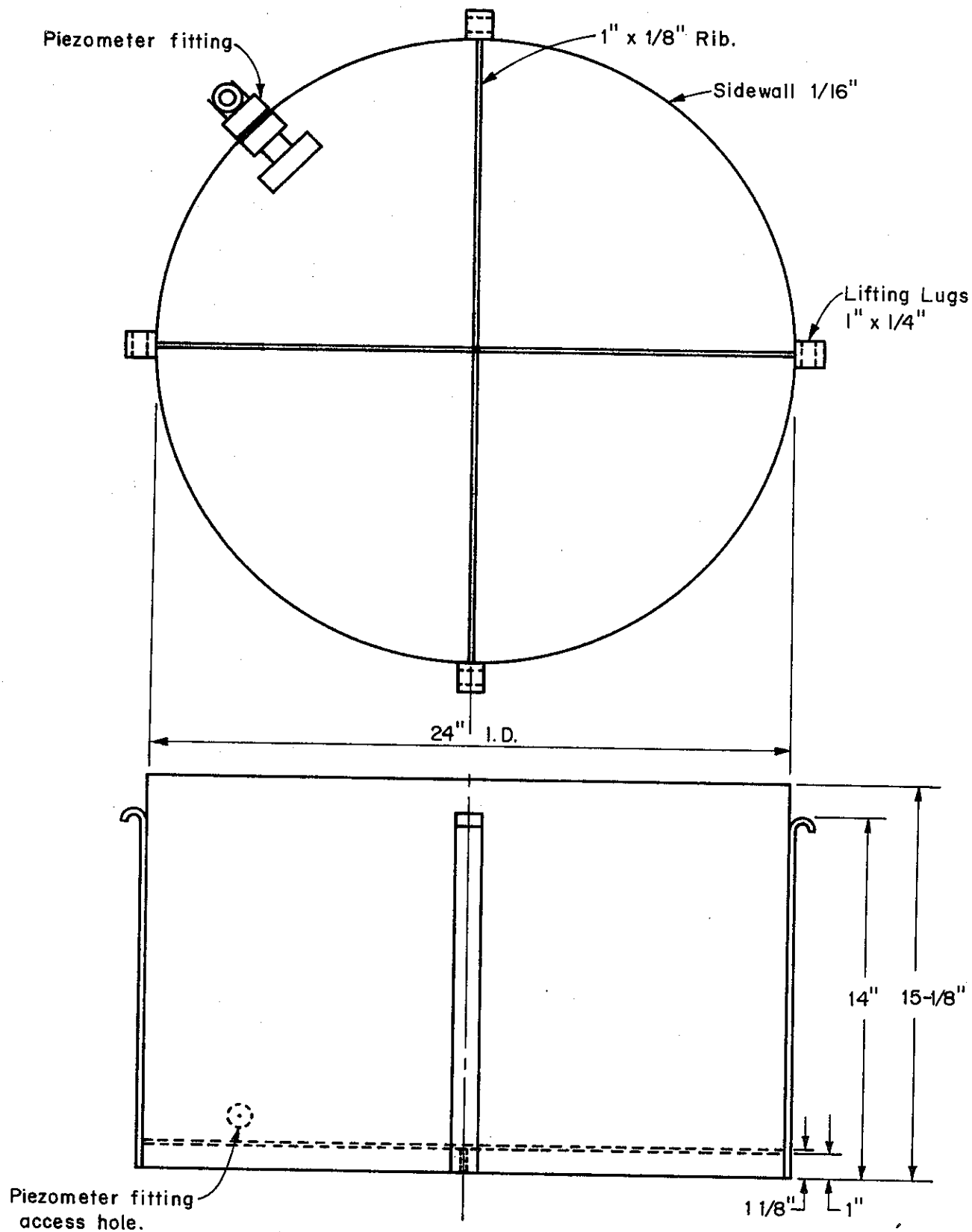


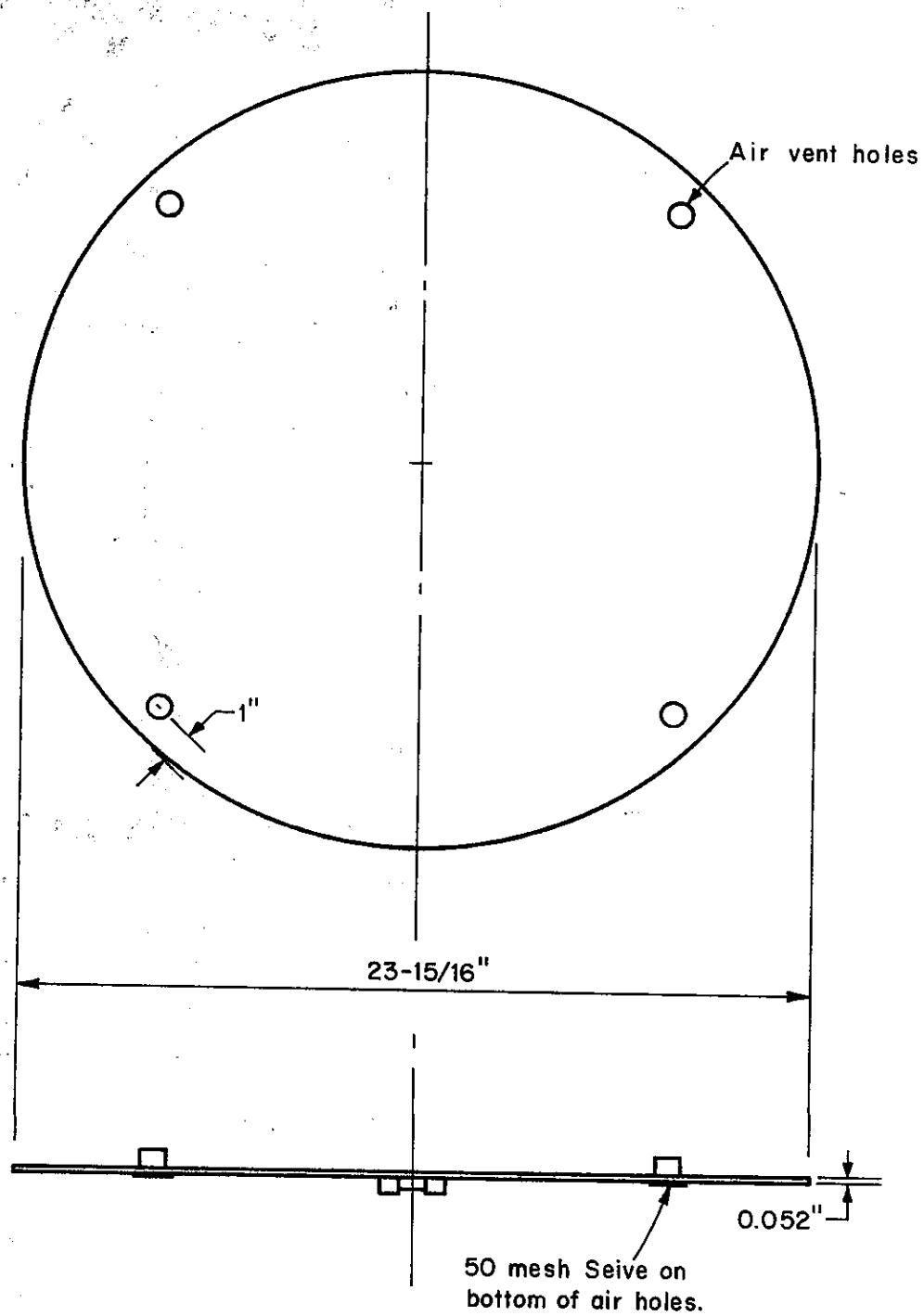
Figure 5



MOISTURE STANDARD TUB

Scale 3/16" = 1"

Figure 6



MOISTURE STANDARD TUB COVER

Scale $\frac{3}{16}" = 1"$

Figure 7

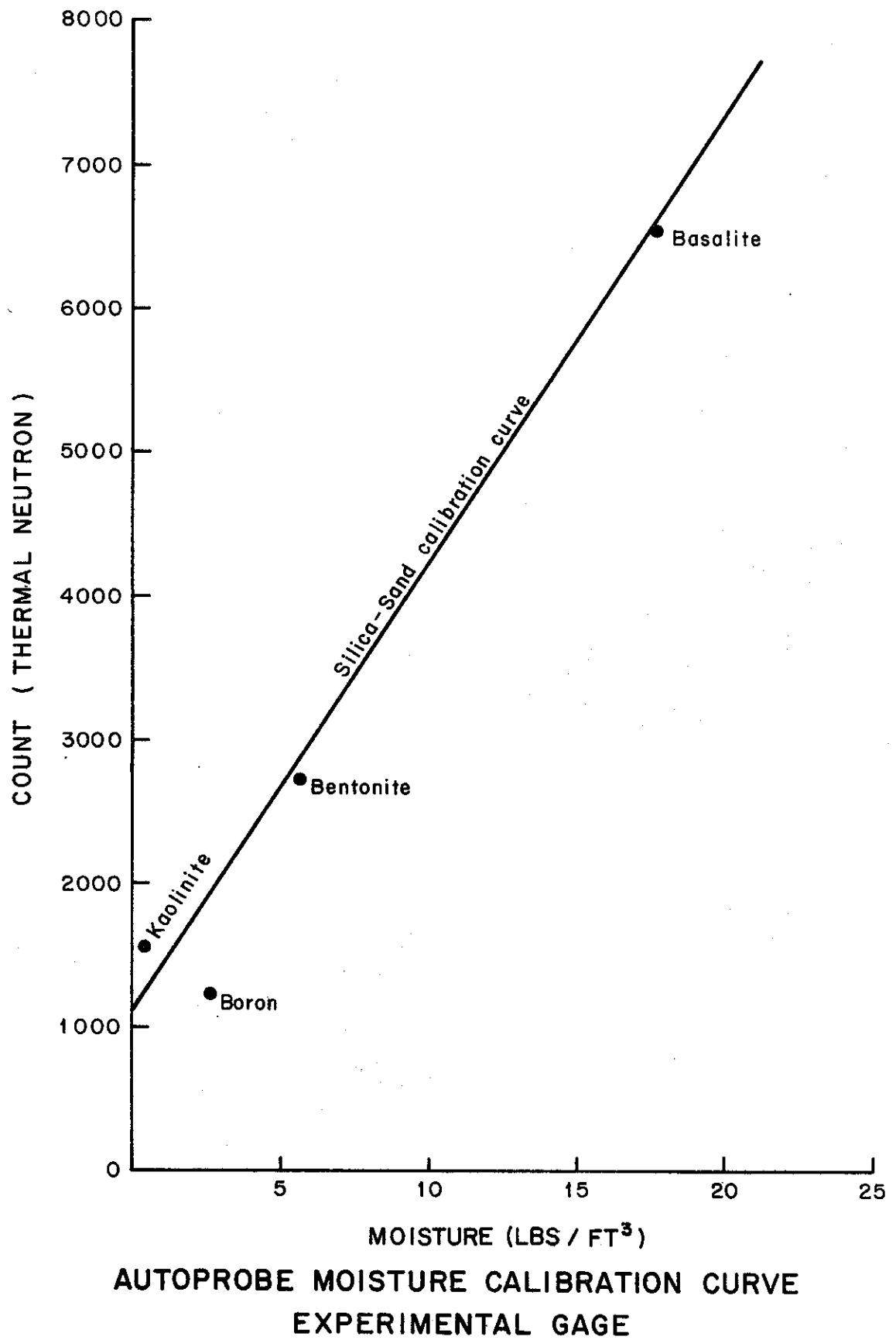


Figure 8

Photo 1 Top view of empty
tub for moisture
standard.

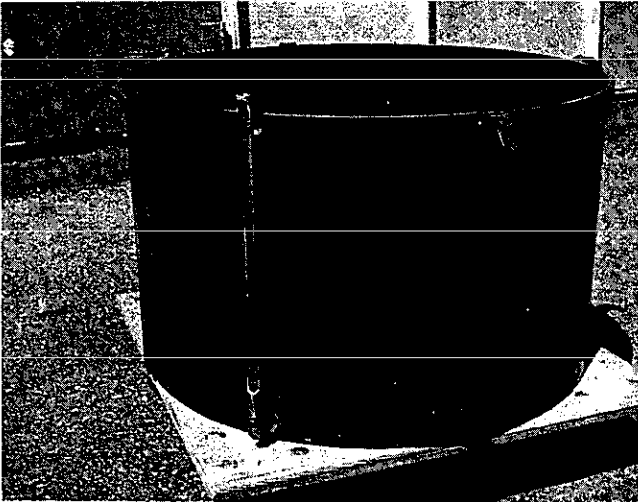
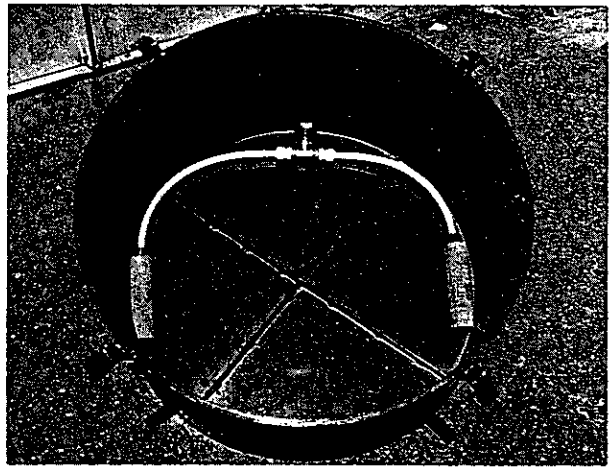


Photo 2 Side View of
empty tub.

Photo 3 Dry Silica Tub and
18.8 #/ft³ Silica
Tub moisture
standards.



METHOD OF DEVELOPING DENSITY AND MOISTURE CALIBRATION TABLES FOR THE NUCLEAR GAGE

Scope

This is a procedure for developing density and moisture calibration tables for nuclear gages. Gage count ratios are related to six California Transportation Laboratory Master Standard Density Blocks (CTLMSDB), located in Sacramento, California. These blocks are the standard reference blocks for the California Department of Transportation.

Density calibration tables may also be developed by relating gage count ratios to two reference standard blocks located in each of the eleven Transportation Districts of the Department of Transportation. Each district block is correlated to the six CTLMSDB at least once every 15 months as described in this procedure.

Moisture calibration tables can be developed by relating gage count ratios to the two moisture standards located at the Transportation Laboratory in Sacramento or to the two moisture standards in each of the eleven Transportation Districts. Correlations to oven dry moistures may be necessary where this relationship is desired.

This method is divided into the following three parts:

Part I. Procedure For Correlating The Six Transportation Laboratory Master Standard Density Blocks and The Two Transportation District Blocks.

Part II. Procedure For Determination Of Direct Transmission and Backscatter Density Calibration Tables.

Part III. Procedure For Determination Of Moisture Calibration Tables.

PART I. PROCEDURE FOR CORRELATING THE SIX TRANSPORTATION LABORATORY BLOCKS AND THE TWO TRANSPORTATION DISTRICT BLOCKS

A. Apparatus

1. All nuclear gages with their standardizing devices in each Transportation District.
2. The six CTLMSDB or the two Transportation blocks maintained in each Transportation District.

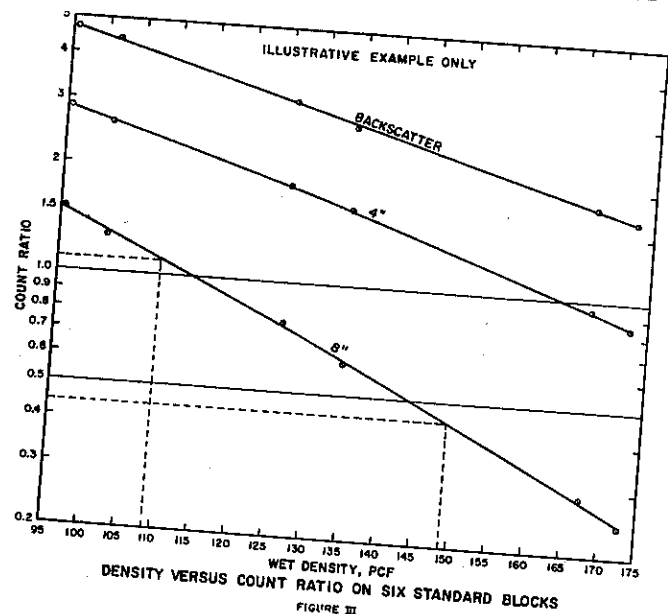
B. Standardization Of Gage For Density

1. Set the standardizing devices five feet from any object and twenty-five feet from any gage. Place the gage on the standardizing device in the safe position for the source in the rod gage and take ten density counts. For the detector in the rod type of gage, see the manufacturer's manual for the correct position for taking standard counts. The ten measurements taken are part of the warmup procedure and are entered in a gage log book but are not used in the subsequent parts

of this procedure. After the warmup, take five or more one minute counts for density. Record the data on Form DH-TL-204A (Figure 1) and in the gage log book. The average of the five measurements is the *standard count* for the gage.

C. Calibration Procedure For Density

1. Set the detector or source rod at the desired depth and position the gage on one of the two Transportation District reference standard blocks with the rod in the hole provided for this purpose. All blocks must be spaced at least twenty-five feet apart unless there is proper shielding between the blocks. Each block should show the exact position of the gage by lines marked on the block.
2. Adjust the gage so that the rod is firmly against the side of the hole nearest to the source (detector tube).
3. Take four or more one minute counts at backscatter, 2, 3, 4, 5, 6, 7 and 8 inch direct transmission modes. Repeat the measurements on the second Transportation District block. Record all data on Form DH-TL-204 A (Figure I).
4. Repeat the steps in C-1, C-2 and C-3 on the six CTLMSDB and record all data on Form DH-TL-204 B (Figure II). Every gage in a Transportation District should be included in this correlation procedure.
5. The calibration data from a gage on the 6 CTLMSDB (Figure II) are plotted as gage count ratios versus known densities of the CTLMSDB. The *count ratio* is the average block count divided by the standard count. The ex-



NOTE: See Section 121 of the Materials Manual For Administrative Instructions regarding use of nuclear gages.

ample on Figure III shows a plot of only the 8 inch reading.

The calibration of the same gage on the two district blocks (Figure I) are plotted so that the count ratio of the gage falls on the average CTLMSDB calibration curve for a particular mode of test (Figure III). The corresponding density for the particular count ratio is then determined by reading the density on the abscissa.

The count ratio for district block No. 6 is 1.091 for the 8-inch direct transmission mode. Draw a line from 1.091 perpendicular to the ordinate until it intersects the average line for the 6-block calibration. Draw a line from the intersection parallel to the ordinate and read a density of 109.0 cf on the abscissa. Following the same procedure, the density for a count ratio of 0.439 is 149.0 pcf.

6. Repeat the above procedure for the count ratios on the two district blocks for all test modes.
7. A tabulation is made of all individual densities for all gages in each district and an average value is calculated for each test mode and each district block (Table I).
8. The assigned values for the district block will be the average value calculated in Step 7 plus 0.5 pounds.
9. Steps C-5 through C-8 can be performed on a computer.
10. No adjustment to the assigned values of the Transportation District blocks shall be made if the annual calibration is within ± 0.5 pcf of the previous year's calibration.

PART II. PROCEDURE FOR DETERMINATION OF DIRECT TRANSMISSION AND BACKSCATTER DENSITY CALIBRATION TABLES

A. Apparatus

1. Nuclear gage and its standardizing device.
2. The six CTLMSDB or the two Transportation District Blocks.

B. Standardization Of Gage For Density

1. Follow the procedure specified in B of Part I.
2. The count ratio (average block count divided by the standard count) related to block density is used for preparing a calibration table. Any subsequent standard count must be within ± 3 standard deviations of the value used to prepare the calibration table. If it is not, the Radiation Administrative Officer will establish a new standard count and prepare a new calibration table or have the gage checked and/or repaired.

NOTE: A standard deviation is defined in this method as $\sigma = \sqrt{n}$; where σ = standard deviation, and n = number of counts indicated on the gage. Table 2 gives an estimate of 3σ for various counts.

C. Calibration Procedure For Density Using the Two Transportation District Blocks

1. Follow the procedure specified in C-1 through C-3 of Part I.
2. Calculate the average of the four counts for each test mode for each block and determine count ratio by dividing the average block count by the standard count (Figure 1).
3. Transmit the count ratios and the assigned values for the two district blocks to the Office of Computer Systems of the California Department of Transportation (Figure IV). Table 3 shows the printout for 8-inch direct transmission mode based on data from the two Transportation District blocks (Figure I).
4. A computer calculated calibration table of count ratios and corresponding densities for each test mode can also be developed using the data from the six CTLMSDB at the Transportation Laboratory in Sacramento, California.

PART III. DETERMINATION OF MOISTURE CALIBRATION TABLES

A. Apparatus

1. Nuclear gage and standardizing device.
2. The two moisture standards located at the Transportation Laboratory in Sacramento or the two moisture standards in each Transportation District of the California Department of Transportation.

B. Calibration Procedure

1. Following the procedure in B-1 of Part I except take moisture readings instead of density readings. Record the data on Form DH-TL-204A (Figure I). The warmup and P.M. standard counts for moisture can be recorded in the space provided for the density standard counts. These counts are not necessary if the density counts were already made during the same day.
2. Place the gage on the moisture standard and take four or more one minute counts.
3. Repeat the test on the second standard.
4. Record the data on Form DH-TL-204A (Figure I), calculate the average and determine count ratio by dividing the average count on the moisture calibration standard by the standard count for moisture.
5. Transmit the count ratios and the assigned values for the moisture standards to the Office of Computer Systems of the California Department of Transportation (Figure IV). Table 4 shows the printout for moisture based on the data shown on Figure I. This table may not give moisture contents comparable to oven drying (Test Method No. Calif. 226). If this correlation is needed, the table must be verified by performing nuclear gage field moisture tests and related to oven dry moistures and field densities.

C. Field Moisture Calibration Procedure

1. Follow Section A and B-1 through B-4 of this Part III.

ILLUSTRATIVE EXAMPLE ONLY

CALIBRATION FOR NUCLEAR GAGE

DISTRICT 06 DATE 5-10-73 TESTS BY PM STANDARD COUNT 41886 GAGE No. 715

	BS	2"	3"	4"	5"	6"	7"	8"
1	197110	122920	124550	119910	106470	92020	77080	62560
2	19840	123360	125070	119210	106420	92220	77230	62560
3	19660	122930	125570	119290	106640	91800	76870	63020
4	19550	122920	125330	119340	106660	91880	77330	63260
Σ	78760	492130	500520	477830	426190	367920	308510	251400
X	19690	123033	125130	119458	106548	91980	77128	62850
CR	0470	2937	2987	2852	2544	2196	1841	1501
1	13120	87100	85180	77740	65910	54180	41940	32340
2	12970	87180	85220	77800	65870	53930	42400	32140
3	13130	86840	85440	77710	66560	53840	42390	32070
4	13190	87410	85450	77820	66300	54010	42500	32390
Σ	52410	348530	341290	310702	264640	215960	162230	128940
X	13103	87133	85323	77768	66160	53990	42308	32235
CR	0313	2080	2037	1857	1580	1289	1010	0770
1	7600	48380	45620	39070	31430	23580	17000	11970
2	7490	48560	45740	39350	31220	23500	16750	11930
3	7520	48930	45780	39560	31040	23460	17250	12060
4	7340	48390	45190	39580	31150	23580	16940	11830
Σ	29950	194260	182330	157560	124840	94120	67940	47790
X	7488	48565	45583	39390	31210	23530	16985	11948
CR	0179	1159	1088	0940	0745	0562	0406	0285
1	18330	11980	117960	108580	95200	80310	66420	52900
2	18380	120140	117930	108330	94860	80760	66620	53310
3	18560	119210	117920	109000	95410	80550	66670	53270
4	18400	119940	118560	108630	94830	80260	66050	52770
Σ	73670	479090	472370	434540	380300	321880	265780	212250
X	18418	119772	118093	108635	95075	80470	66445	53063
CR	0440	2859	2819	2594	2270	1921	1586	1267
1	11390	77590	75010	67860	55370	43830	33810	25610
2	11360	77520	74960	67810	55560	44160	34020	25700
3	11500	77850	75240	67710	55660	44350	33920	25700
4	11480	77460	74960	68020	56040	44290	34210	25420
Σ	45730	1042030	1001702	714002	222630	176630	135960	102430
X	11433	77605	75043	67850	55658	44158	34990	25608
CR	0273	1853	1792	1620	1329	1055	0811	0611
1	7000	44810	41530	35510	27750	21000	15160	10320
2	7030	44920	41690	35620	28250	20880	14830	10270
3	6910	44790	41910	35130	27810	20840	14930	10160
4	6890	44770	41540	35440	27950	20720	15110	10180
Σ	27830	179290	166670	141700	11760	83440	60030	40930
X	6958	44823	41668	35425	27940	20860	15008	10233
CR	0166	11070	0995	0846	0667	0498	0358	0244

DH-TL-204B (Rev. 8-73)

FIGURE II

ILLUSTRATIVE
EXAMPLE ONLY

TABLE 1
CORRELATION OF DISTRICT TO TRANSPORTATION LABORATORY DENSITY BLOCKS

DISTRICT 06 DATE 6-1-73 BY M H

GAGE NUMBER	BACKSCATTER		2"		3"		4"	
	L	H	L	H	L	H	L	H
715	115.5	155.5	112.5	152.2	110.9	151.0	110.0	150.0
C25	114.9	154.3	112.3	152.1	111.2	151.7	110.5	151.5
713	116.8	156.5	112.2	151.2	110.6	150.3	111.0	150.8
C39	114.3	156.8	112.8	153.0	111.0	151.3	110.5	151.3
C42	116.0	156.0	113.0	153.8	111.7	151.8	113.3	152.0
726	116.0	156.0	113.5	153.8	112.0	151.5	111.2	152.0
C44	114.5	153.3	112.0	153.1	111.5	150.9	112.0	151.3
735	113.8	154.8	113.3	153.2	111.2	151.3	111.8	151.2
Σ	921.8	1244.2	901.6	1222.4	890.1	1209.8	890.3	1210.1
\bar{X}	115.2	155.5	112.7	152.8	111.3	151.2	111.3	151.3
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Assigned Value	115.7	156.0	113.2	153.3	111.8	151.7	111.8	151.8

ILLUSTRATIVE
EXAMPLE ONLY

TABLE 1 (Continued)
CORRELATION OF DISTRICT TO TRANSPORTATION LABORATORY DENSITY BLOCKS

DISTRICT 06 DATE 6-1-73 BY MH

GAGE NUMBER	5"		6"		7"		8"	
	L	H	L	H	L	H	L	H
715	110.0	150.4	110.5	150.0	110.5	149.2	110.0	149.0
C25	110.0	151.0	110.7	150.3	112.0	150.0	111.8	149.3
713	110.0	149.5	111.0	149.0	111.2	148.3	111.0	148.4
C39	110.0	151.0	110.0	150.0	111.2	149.8	110.0	149.0
C42	111.0	150.8	111.3	150.8	112.0	150.2	111.6	149.5
726	111.0	151.2	111.9	150.6	112.0	149.9	112.1	149.5
C44	110.9	150.3	110.5	149.8	112.0	149.7	109.9	150.2
735	110.8	151.5	110.8	150.2	111.0	149.8	111.0	149.2
Σ	883.5	1205.7	886.7	1200.7	891.9	1196.9	887.4	1194.1
\bar{X}	110.4	150.7	110.8	150.1	111.5	149.6	110.9	149.3
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Assigned Value	110.9	151.2	111.3	150.6	112.0	150.1	111.4	149.8

TABLE 2
STANDARD DEVIATION FOR VARIOUS GAGE COUNTS

N	3σ	N	3σ	N	3σ	N	3σ	N	3σ
≤10,100	300								
10100-10302	303	19740-20022	423	32580-32942	543	48620-49062	663	67860-68382	783
10302-10506	306	20022-20306	426	32942-33306	546	49062-49506	666	68382-68906	786
10506-10712	309	20306-20592	429	33306-33672	549	49506-49952	669	68906-69432	789
10712-10920	312	20592-20880	432	33672-34040	552	49952-50400	672	69432-69960	792
10920-11130	315	20880-21170	435	34040-34410	555	50400-50850	675	69960-70490	795
11130-11342	318	21170-21462	438	34410-34782	558	50850-51302	678	70490-71022	798
11342-11556	321	21462-21756	441	34782-35156	561	51302-51756	681	71022-71556	801
11556-11772	324	21756-22052	444	35156-35532	564	51756-52212	684	71556-72092	804
11772-11990	327	22052-22350	447	35532-35910	567	52212-52670	687	72092-72630	807
11990-12210	330	22350-22650	450	35910-36290	570	52670-53130	690	72630-73170	810
12210-12432	333	22650-22952	453	36290-36672	573	53130-53592	693	73170-73712	813
12432-12656	336	22952-23256	456	36672-37056	576	53592-54056	696	73712-74256	816
12656-12882	339	23256-23562	459	37056-37442	579	54056-54522	699	74256-74802	819
12882-13110	342	23562-23870	462	37442-37830	582	54522-54990	702	74802-75350	822
13110-13340	345	23870-24180	465	37830-38220	585	54990-55460	705	75350-75900	825
13340-13572	348	24180-24492	468	38220-38612	588	55460-55932	708	75900-76452	828
13572-13806	351	24492-24806	471	38612-39006	591	55932-56406	711	76452-77006	831
13806-14042	354	24806-25122	474	39006-39402	594	56406-56882	714	77006-77562	834
14042-14280	357	25122-25440	477	39402-39800	597	56882-57360	717	77562-78120	837
14280-14520	360	25440-25760	480	39800-40200	600	57360-57840	720	78120-78680	840
14520-14762	363	25760-26082	483	40200-40602	603	57840-58322	723	78680-79242	843
14762-15006	366	26082-26406	486	40602-41006	606	58322-58806	726	79242-79806	846
15006-15252	369	26406-26732	489	41006-41412	609	58806-59292	729	79806-80372	849
15252-15500	372	26732-27060	492	41412-41820	612	59292-59780	732	80372-80940	852
15500-15750	375	27060-27390	495	41820-42230	615	59780-60270	735	80940-81510	855
15750-16002	378	27390-27722	498	42230-42642	618	60270-60762	738	81510-82082	858
16002-16256	381	27722-28056	501	42642-43056	621	60762-61256	741	82082-82656	861
16256-16512	384	28056-28392	504	43056-43472	624	61256-61752	744	82656-83232	864
16512-16770	387	28392-28730	507	43472-43890	627	61752-62250	747	83232-83810	867
16770-17030	390	28730-29070	510	43890-44310	630	62250-62750	750	83810-84390	870
17030-17292	393	29070-29412	513	44310-44732	633	62750-63252	753	84390-84972	873
17292-17556	396	29412-29756	516	44732-45156	636	63252-63756	756	84972-85556	876
17556-17822	399	29756-30102	519	45156-45582	639	63756-64262	759	85556-86142	879
17822-18090	402	30102-30450	522	45582-46010	642	64262-64770	762	86142-86730	882
18090-18360	405	30450-30800	525	46010-46440	645	64770-65280	765	86730-87320	885
18360-18632	408	30800-31152	528	46440-46872	648	65280-65792	768	87320-87912	888
18632-18906	411	31152-31506	531	46872-47306	651	65792-66306	771	87912-88506	891
18906-19182	414	31506-31862	534	47306-47742	654	66306-66822	774	88506-89102	894
19182-19460	417	31862-32220	537	47742-48180	657	66822-67340	777	89102-89700	897
19460-19740	420	32220-32580	540	48180-48620	660	67340-67860	780	89700-90300	900

NUCLEAR GAGE CALIBRATION DATA INPUT FORM

LINE TYPE	DIST	DATE	SUBMITTER	GAGE	COMMENT	LINE
I 06	2 4	MAY 10 1973	P. MONAHAN	715		76 77 80
LINE TEST TYPE CODE	STANDARD COUNT	BLOCK 1 DENSITY	BLOCK 1 COUNT RATIO	BLOCK 2 DENSITY	BLOCK 2 COUNT RATIO	COMMENT
D 8	41886	111.4	1.091	149.8	0.439	
D M	5560	0.0	0.080	18.8	0.777	
2 5	11 15	21	30 31	40 41	50 51	76 77 80

FIGURE IV

LINE TYPE	DIST	DATE	SUBMITTER	GAGE	COMMENT	LINE
2 4	9	20	37 38	45 46		76 77 80
LINE TEST TYPE CODE	STANDARD COUNT	BLOCK 1 DENSITY	BLOCK 1 COUNT RATIO	BLOCK 2 DENSITY	BLOCK 2 COUNT RATIO	COMMENT
2 5	11 15	21	30 31	40 41	50 51	76 77 80

TEST CODES: 2, 3, 4, 5, 6, 7, 8 = PROBE DEPTHS, DIRECT TRANSMISSION
 B = BACKSCATTER M = MOISTURE

DEPARTMENT

ROOM

HCS 130 (REV 6/72)

IN CASE OF QUESTION CONTACT:

NAME

PHONE

DATE

VERIFY

PAGE OF

TABLE 3

COUNT RATIO VS DENSITY FOR NUCLEAR GAGE NO. 715

DIST. 6 10 MAY 73 STD. CT 41886
 BASED ON: DENSITY PCF 111.4 149.8
 G/CC 1.784 2.399
 COUNT RATIO 1.091 .439

8 IN D/T BY P. MONAHAN

$$PCF = (G/CC) \times (62.43)$$

CR	TO	CR	G/CC	CR	TO	CR	G/CC	CR	TO	CR	G/CC
1.869	-	1.895	1.40	1.060	-	1.074	1.80	.592	-	.601	2.20
1.843	-	1.868	1.41	1.045	-	1.059	1.81	.583	-	.591	2.21
1.817	-	1.842	1.42	1.030	-	1.044	1.82	.574	-	.582	2.22
1.792	-	1.816	1.43	1.015	-	1.029	1.83	.566	-	.573	2.23
1.766	-	1.791	1.44	1.001	-	1.014	1.84	.557	-	.565	2.24
1.741	-	1.765	1.45	.987	-	1.000	1.85	.548	-	.556	2.25
1.717	-	1.740	1.46	.973	-	.986	1.86	.540	-	.547	2.26
1.693	-	1.716	1.47	.959	-	.972	1.87	.532	-	.539	2.27
1.669	-	1.692	1.48	.946	-	.958	1.88	.524	-	.531	2.28
1.645	-	1.668	1.49	.932	-	.945	1.89	.516	-	.523	2.29
1.622	-	1.644	1.50	.919	-	.931	1.90	.508	-	.515	2.30
1.599	-	1.621	1.51	.906	-	.918	1.91	.500	-	.507	2.31
1.577	-	1.598	1.52	.894	-	.905	1.92	.492	-	.499	2.32
1.554	-	1.576	1.53	.881	-	.893	1.93	.485	-	.491	2.33
1.533	-	1.553	1.54	.869	-	.880	1.94	.477	-	.484	2.34
1.511	-	1.532	1.55	.856	-	.868	1.95	.470	-	.476	2.35
1.490	-	1.510	1.56	.844	-	.855	1.96	.463	-	.469	2.36
1.469	-	1.489	1.57	.832	-	.843	1.97	.456	-	.462	2.37
1.448	-	1.468	1.58	.821	-	.831	1.98	.449	-	.455	2.38
1.428	-	1.447	1.59	.809	-	.820	1.99	.442	-	.448	2.39
1.407	-	1.427	1.60	.798	-	.808	2.00	.435	-	.441	2.40
1.388	-	1.406	1.61	.786	-	.797	2.01	.429	-	.434	2.41
1.368	-	1.387	1.62	.775	-	.785	2.02	.422	-	.428	2.42
1.349	-	1.367	1.63	.764	-	.774	2.03	.416	-	.421	2.43
1.330	-	1.348	1.64	.754	-	.763	2.04	.409	-	.415	2.44
1.311	-	1.329	1.65	.743	-	.753	2.05	.403	-	.408	2.45
1.293	-	1.310	1.66	.733	-	.742	2.06	.397	-	.402	2.46
1.274	-	1.292	1.67	.722	-	.732	2.07	.391	-	.396	2.47
1.256	-	1.273	1.68	.712	-	.721	2.08	.385	-	.390	2.48
1.239	-	1.255	1.69	.702	-	.712	2.09	.379	-	.384	2.49
1.221	-	1.238	1.70	.691	-	.701	2.10	.373	-	.378	2.50
1.204	-	1.220	1.71	.680	-	.690	2.11	.367	-	.372	2.51
1.187	-	1.203	1.72	.670	-	.679	2.12	.362	-	.366	2.52
1.170	-	1.186	1.73	.660	-	.669	2.13	.356	-	.361	2.53
1.154	-	1.169	1.74	.650	-	.659	2.14	.351	-	.355	2.54
1.137	-	1.153	1.75	.640	-	.649	2.15	.345	-	.350	2.55
1.121	-	1.136	1.76	.630	-	.639	2.16	.340	-	.344	2.56
1.106	-	1.120	1.77	.620	-	.629	2.17	.335	-	.339	2.57
1.090	-	1.105	1.78	.611	-	.619	2.18	.330	-	.334	2.58
1.075	-	1.089	1.79	.602	-	.610	2.19	.325	-	.329	2.59

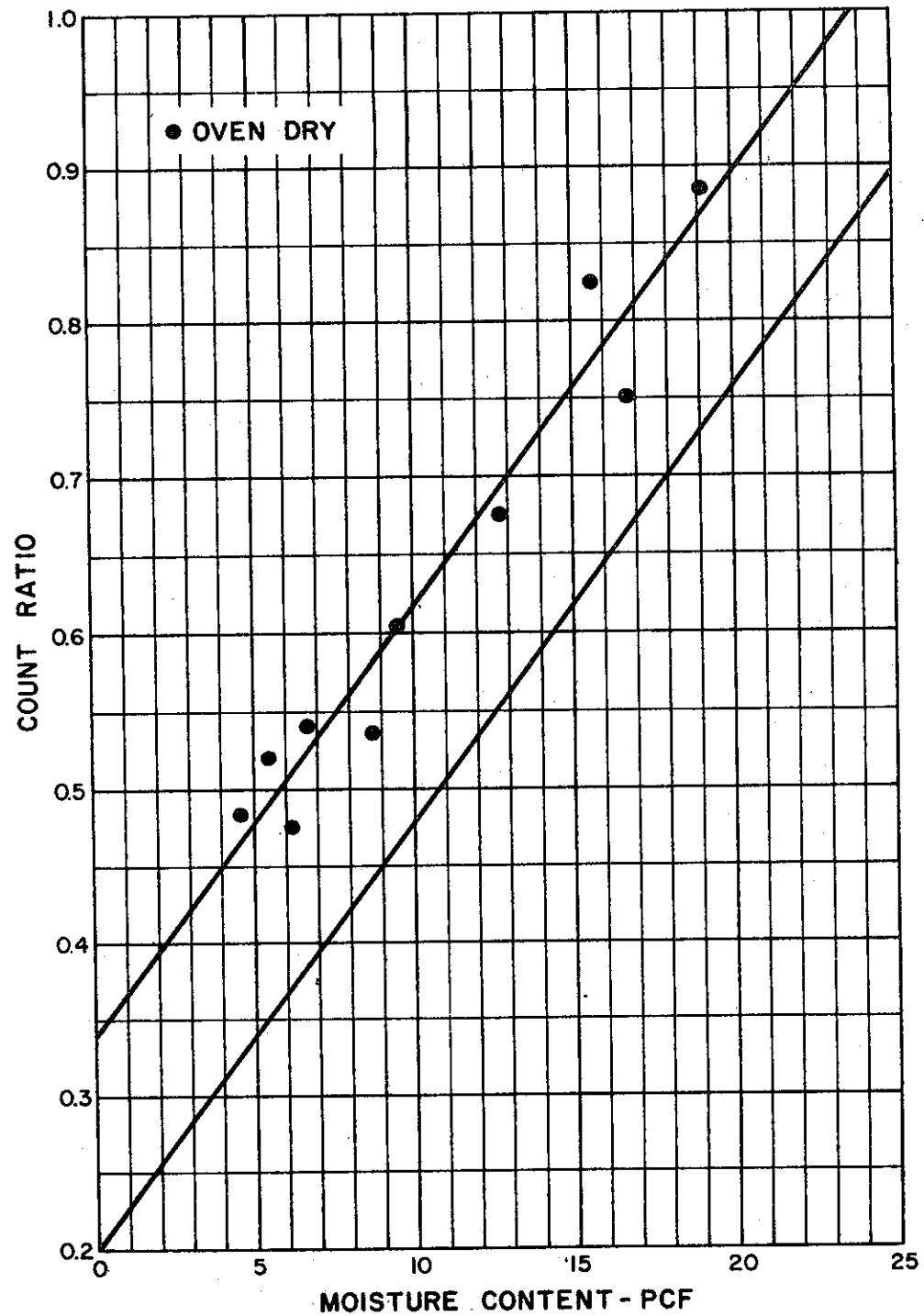
TABLE 4

COUNT RATIO VS MOISTURE FOR NUCLEAR GAGE NO. 715

DIST. 6		10 MAY 73		STD. CT 5560		BY P. MCNAHAN	
BASED ON: MOISTURE PCF		.0		18.8			
		G/CC		.000		.301	
		COUNT RATIO		.080		.777	
						PCF=(G/CC) X (62.43)	
CR	TO	CR	G/CC	CR	TO	CR	G/CC
.069	-	.092	.00	.532	-	.554	.20
.093	-	.115	.01	.555	-	.578	.21
.116	-	.138	.02	.579	-	.601	.22
.139	-	.161	.03	.602	-	.624	.23
.162	-	.184	.04	.625	-	.647	.24
.185	-	.207	.05	.648	-	.670	.25
.208	-	.230	.06	.671	-	.693	.26
.231	-	.254	.07	.694	-	.717	.27
.255	-	.277	.08	.718	-	.740	.28
.278	-	.300	.09	.741	-	.763	.29
.301	-	.323	.10	.764	-	.786	.30
.324	-	.346	.11	.787	-	.809	.31
.347	-	.369	.12	.810	-	.832	.32
.370	-	.392	.13	.833	-	.855	.33
.393	-	.416	.14	.856	-	.879	.34
.417	-	.439	.15	.880	-	.902	.35
.440	-	.462	.16	.903	-	.925	.36
.463	-	.485	.17	.926	-	.948	.37
.486	-	.508	.18	.949	-	.971	.38
.509	-	.531	.19	.972	-	.994	.39
.995	-	1.017	.40				
1.018	-	1.041	.41				
1.042	-	1.064	.42				
1.065	-	1.087	.43				
1.088	-	1.110	.44				
1.111	-	1.133	.45				
1.134	-	1.156	.46				
1.157	-	1.179	.47				
1.180	-	1.203	.48				
1.204	-	1.226	.49				
1.227	-	1.249	.50				
1.250	-	1.272	.51				
1.273	-	1.295	.52				
1.296	-	1.318	.53				
1.319	-	1.341	.54				
1.342	-	1.365	.55				
1.366	-	1.388	.56				
1.389	-	1.411	.57				
1.412	-	1.434	.58				
1.435	-	1.457	.59				

ILLUSTRATIVE
EXAMPLE ONLY

MOISTURE CALIBRATION CURVE



October 7, 1974

2. Plot the data from B-4 and draw a curve (Figure V).
3. Take at least 10 nuclear gage field moisture and density tests (Test Method No. Calif. 231).
4. At these same sites, take representative soils samples and determine oven dry moistures (Test Method No. Calif. 226).
5. Plot the field gage count ratios versus field moistures (Figure V).
6. Draw a best fit curve through the points and parallel to the standard curve determined in C-2 of this Part III.

7. Take a count ratio at 0.3 and 1.0 and the corresponding moistures at these two points. Transmit this data to the Office of Computer Systems for a computer calculated table of moistures and count ratios.

Each gage should be checked for density and moisture calibration at least once a year, or oftener if variations in standard counts exceed the limits of Part II-B or when the gage is repaired.

REFERENCES

Test Method Nos. Calif. 220, 231 and Section 121 of the Materials Manual.

End of Text on Calif. 911-C

